5408

Copy No. 12

NATIONAL BUREAU OF STANDARDS REPORT

5908

CAPACITY TESTS OF A MATHES HEAT PUMP
MODEL 38HAR-VEB-HP

by

Joseph C. Davis
Paul R. Achenbach

Report to
Seymour Johnson Air Force Base
Goldsboro, North Carolina

NBS

U. S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

FOR OFFICIAL USE ONLY

THE NATIONAL BUREAU OF STANDARDS

Functions and Activities

The functions of the National Bureau of Standards are set forth in the Act of Congress, March 3, 1901, as amended by Congress in Public Law 619, 1950. These include the development and maintenance of the national standards of measurement and the provision of means and methods for making measurements consistent with these standards; the determination of physical constants and properties of materials; the development of methods and instruments for testing materials, devices, and structures; advisory services to Government Agencies on scientific and technical problems; invention and development of devices to serve special needs of the Government; and the development of standard practices, codes, and specifications. The work includes basic and applied research, development, engineering, instrumentation, testing, evaluation, calibration services, and various consultation and information services. A major portion of the Bureau's work is performed for other Government Agencies, particularly the Department of Defense and the Atomic Energy Commission. The scope of activities is suggested by the listing of divisions and sections on the inside of the back cover.

Reports and Publications

The results of the Bureau's work take the form of either actual equipment and devices or published papers and reports. Reports are issued to the sponsoring agency of a particular project or program. Published papers appear either in the Bureau's own series of publications or in the journals of professional and scientific societies. The Bureau itself publishes three monthly periodicals, available from the Government Printing Office: The Journal of Research, which presents complete papers reporting technical investigations; the Technical News Bulletin, which presents summary and preliminary reports on work in progress; and Basic Radio Propagation Predictions, which provides data for determining the best frequencies to use for radio communications throughout the world. There are also five series of nonperiodical publications: The Applied Mathematics Series, Circulars, Handbooks, Building Materials and Structures Reports, and Miscellaneous Publications.

Information on the Bureau's publications can be found in NBS Circular 460, Publications of the National Bureau of Standards ($1.25) and its Supplement ($0.75), available from the Superintendent of Documents, Government Printing Office, Washington 25, D. C.

Inquiries regarding the Bureau's reports should be addressed to the Office of Technical Information, National Bureau of Standards, Washington 25, D. C.

NATIONAL BUREAU OF STANDARDS REPORT

NBS PROJECT | **NBS REPORT**

1000-30-4830 | May 27, 1958 | 5908

CAPACITY TESTS OF A MATHES HEAT PUMP
MODEL 38HAR-VEB-HP

by

Joseph C. Davis
Paul R. Achenbach

Air Conditioning, Heating, and Refrigeration Section
Building Technology Division

to
Seymour Johnson Air Force Base
Goldsboro, North Carolina

U. S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

CAPACITY TESTS OF A MATHES HEAT PUMP,
MODEL 38HAR-VEB-HP

by

Joseph C. Davis and Paul R. Achenbach

ABSTRACT

At the request of the Contracting Officer, Seymour Johnson Air Force Base, cooling and heating capacity tests were made of a Mathes air-to-air heat pump, Model 38HAR-VEB-HP. These tests were made at the indoor and outdoor conditions stated in the contract specifications and, except for minor deviations, in accordance with the procedures and conditions specified by the American Society of Refrigerating Engineers Standard No. 16-56. The observed cooling capacity was 34,500 Btu/hr at the specified test conditions whereas the minimum required was 36,000 Btu/hr. The observed heating capacity, without supplementary strip heaters was 24,000 Btu/hr at an outdoor temperature of 20°F, whereas the minimum required was 30,500 Btu/hr. At rated voltage the two strip heaters furnished with the unit had a capacity of 3.3 KW as compared to the requirement of 3.6 KW. At the request of the Mathes Company a test was made with the outdoor temperature at 30°F. Capacity for this outdoor temperature was 27,400 Btu/hr.

1. INTRODUCTION

In accordance with a request from Captain W. A. Schrontz, Contracting Officer, Seymour Johnson Air Force Base, United States Air Force, by letter dated August 22, 1957, tests were made to determine the cooling and heating capacity of a Mathes Heat Pump, Model 38 HAR-VEB-HP. These tests represented the third phase of a series of tests on several models of heat pumps that will be used at this site. Results of the tests for the first two models are covered in National Bureau of Standards Report No. 5818, "Capacity Tests of Mathes Heat Pump Model 38HAR-LEB-HP," and No. 5885, "Capacity Tests of Mathes Heat Pump Model 27HAR-REB-HP."

Specifications supplied by Captain Schrontz, Section 27A-Heat Pumps Alternate of the contract specifications and drawings for homes under construction at Seymour Johnson Air Force Base, require a total cooling capacity for this model of 36,000 Btu/hr and a total heating capacity of 42,786 Btu/hr. A breakdown of the capacity requirements for these two conditions follows:

COOLING CAPACITY (Btu/hr)

Sensible	Latent	Total
25,200	10,800	36,000

HEATING CAPACITY (Btu/hr)

Condenser Heat Transfer	From Supplementary Strip Heaters	Total
30,500	12,286	42,786

In a letter from Captain Schrontz dated April 3, 1958, four 1.8 KW supplementary resistance heaters were specified as conditions of testing the Model 38HAR-VEB-HP Mathes heat pump. With these heaters, the total required supplementary heating capacity would be 24,572 Btu/hr.

The specifications also require that the minimum air circulation rate be 1,300 cfm against an external static resistance of 0.2 in. of water.

2. DESCRIPTION OF TEST SPECIMEN

The model 38HAR-VEB-HP heat pump is known as a "split-type" unit in which one section is placed outdoors and the other inside the home at a suitable place for delivering conditioned air. This heat pump is essentially the same as the 38HAR-LEB-HP recently tested except for capillary tube size in the outdoor unit and the fact that the conditioned air is discharged in a vertical direction from the indoor unit instead of in a horizontal direction.

During the cooling cycle, the coil of the indoor unit served as an evaporator, absorbing heat; and during the heating cycle, as a condenser, rejecting heat. This operational change was accomplished by means of a change in direction of circulation of the refrigerant through the system, using a thermostatically-controlled solenoid in a four-way valve. During the test the solenoid was controlled by a manually operated switch to preclude shifting from cooling to heating or vice versa. Capillary tubes were used as the liquid refrigerant flow control device in both the indoor and outdoor units with check-valves to by-pass each when not needed. Following the new ASRE refrigerant designations, the refrigerant was R-22.

A schematic diagram of the heat pump system and auxiliary test instrumentation is shown in figure 1. The oil separator was shown in this figure for purposes of explanation, but was not used during the tests. A list of line sizes for this system without the separator is shown below:

		Size OD (in.)
1.	Compressor discharge to 4-way valve	1/2
2.	Compressor suction to 4-way valve	7/8
3.	Four-way valve to coil of outdoor unit	7/8
4.	Liquid line to flowmeter manifold	3/8
5.	Lines in manifold	1/2
6.	Vapor line	7/8

The indoor unit consisted essentially of a coil (used as an evaporator during cooling), a blower for circulating conditioned air through the duct system of the home, and a capillary tube - check valve assembly. The coil was a three-row coil, 30 in. wide and 28.25 in. high, with 13 fins per in. of tube length. Because of the vertical discharge of conditioned air this coil was positioned at an angle of 45° from vertical, rather than in a vertical position as in the case of units discharging air horizontally. A Torrington blower with a 13-in. diameter wheel was used and it was powered by an Emerson 1/3 HP single phase motor, Model No. S60CXBRT. Nameplate rating of the motor was 230 volts, 60 cycle, 2.7 amperes, with a service factor of 1.35. Speed of rotation of the motor was designated as 1725 rpm. The capillary tube had an ID of 0.1195 in. and was 60 in. long. The housing of the indoor unit was 28.25 in. wide, 30 in. deep and 50 in. high. Wall thickness was 0.05 in. Differing from the horizontal 38HAR-LEB-HP model, the intake filter of this unit was covered with a louvered door.

With the indoor pulley adjusted after the test for about 1300 cfm air delivery, and with the temperature about 75°F, the blower speed of rotation was 760 rpm.

The outdoor unit, with the exception of a smaller capillary tube for heating, was the identical unit used for the first heat pump tested, Model 38HAR-LEB-HP. It consisted essentially of a coil (used as an evaporator during heating); a propeller fan; a hermetically-sealed Tecumseh motor compressor, No. PJE-300, 230 volts, 50/60 cycles, single phase, full load amperage of 21.0; a capillary tube - check valve assembly; and a four-way valve. The coil had 2 rows, 13 fins per in. and was 28 in. high and 49 1/2 in. wide. The fan blade assembly, 24 inches in diameter with a 40° pitch for each blade, was powered by a 1/3 HP, single phase motor. Nameplate rating of the motor was 208-230 volts, 2.7 amperes, with a service factor of 1.36, and rotational speed rating of 1725 rpm. The capillary tube had an ID of 0.0895 in. and a length of 82 in. The housing of the outdoor unit was 51 in. wide, 27 in. deep, and 31 in. high. Wall thickness was 0.090 in. This unit with grilled panel removed is shown in figure 2.

Measurements of the outdoor fan speed at an outdoor temperature of about 75°F showed 800 rpm.

Figure 3 shows the opposite side of the outdoor unit facing the coil. Note the five-in-one thermocouple system and the thermostat used for controlling outdoor conditions during the test.

No modifications of the heat pump were made by the manufacturer during the test.

3. METHODS OF TESTING

Except for minor modifications, the heat pump was tested under the conditions described in ASRE Testing and Rating Standard No. 16-56, as required by the specification. Fig. 4 shows the enclosure housing the indoor unit and the 33-in. square test duct attached to the outlet side of the unit. The indoor unit was tested with the strip heater and electrical assembly removed. This assembly is shown underneath the duct in the figure. Note the two strip heaters, the number standard with this model. This duct housed the nozzle used for measuring air circulation rate and the instruments for measuring temperature and humidity of the outlet air. Because the nozzle mixing baffles, and screen introduced excessive resistance in the outlet duct, an auxiliary blower powered by a one-HP motor was provided at the downstream end of the 33-in duct. By adjustment of a wooden slide-type damper at the outlet of the auxiliary blower the static resistance imposed upon the unit blower was adjusted to 0.20 in. of water. The system including the auxiliary blower, return air heaters, and humidifier used for the tests on the 38HAR-LEB-HP and the 27HAR-REB-HP is shown in figure 5. The same system was used for this test except that the 33-in. duct and auxiliary motor were raised to a level of about six feet to accommodate the comparatively tall vertical type indoor unit.

ASRE Standard 16-56 requires that two independent measuring methods be used during the test, each as a check on the other. One method, known as the psychrometric method, involves measuring the mass-flow of air through the indoor unit

and the change in enthalpy of the air across the unit. The other method involved determination of the flow of refrigerant through the indoor coil and the change in enthalpy of the refrigerant across the indoor coil. A correction to the total enthalpy change of the refrigerant is necessary, either by adding or subtracting the heat equivalent of the electrical energy supplied to the indoor blower motor, depending on which cycle is under operation, before comparing it with the result of the psychrometric method. Values obtained by the two methods must not differ by more than six percent in order for a test to be valid.

Mass flow of air in the psychrometric method was obtained by measuring humidity and temperature conditions of the air entering the nozzle and the static pressure drop across the nozzle. Enthalpy change of the air was determined by measuring temperature, humidity, and barometric pressure of the air entering the indoor unit, and in the duct immediately after it left the unit.

Flow of refrigerant was measured by means of a flowmeter in the liquid line of the system--a Potter Electronic type with and impeller which generated an electrical pulse on each revolution. A Potter counter coupled to the flowmeter served to translate the pulses into gal/unit time. By knowing temperature of the liquid in the line, the flow was converted to mass flow. Enthalpy change was determined by temperature and pressure measurements at the inlet and outlet of the indoor coil. For accurate measurement of capacity by the refrigerant flow method it was imperative that there be no gas bubbles in the liquid refrigerant as it passed through the meter, and that the liquid refrigerant all be evaporated in the coil.

In all tests it was necessary that substantially oil-free refrigerant be supplied to the flowmeter or that the rate of oil circulation be determined. In the tests for the 38HAR-LEB-HP and 27HAR-REB-HP, this was accomplished by placing an oil separator in the hot gas line between the compressor and four-way valve to separate the oil. The oil was returned to the refrigerant at the inlet to the indoor coil during the cooling test and at the inlet of the outdoor coil during the heating test. Note this equipment in figure 1.

In the test of the Model 38HAR-VEB-HP, however, at the request of the Mathes Company, the oil separator was left out of the system, the oil return lines pinched off, and the oil was allowed to pass with the refrigerant through the flowmeter. The amount of oil circulated and the necessary correction to be made were determined by sampling the refrigerant immediately following the cooling test. The refrigerant taken from the line while the heat pump was operating was discharged into special flasks pre-cooled by dry ice, and then allowed to evaporate slowly as the ice melted, leaving a residue of oil.

Each of two samples showed less than 0.2 percent of oil by volume which was insignificant. The oil-refrigerant sampling method of correcting for oil circulation is the method specified in ASRE Standard 16-56, and is considered satisfactory by the National Bureau of Standards. It does require replacement of the refrigerant taken for the oil determination.

It was possible to maintain "state" conditions for both cooling and heating with the use of a test structure having two controlled-temperature spaces.

The following "state" conditions for the indoor and outdoor air were maintained during the cooling cycle in accordance with contract specifications:

95°F DB outdoors
80°F DB inside
67°F WB inside (50 percent relative humidity)

Refrigerant charge was the same for the cooling test as for the heating test. The Mathes Company, having chosen to make the cooling test first, adjusted the refrigerant so that about 1° superheat was obtained at the indoor coil under the "state" conditions specified above.

FOR OFFICIAL USE ONLY.

The heating test was performed on the day following. Because refrigerant was removed from the system to determine oil content as described above, the "state" conditions of 95°DB, 80°DB, and 50 percent relative humidity, were established and refrigerant restored so that temperatures and pressures were substantially the same as those on the cooling test. The heating test was performed within five hours thereafter.

The following "state" conditions for heating were maintained in accordance with the contract specifications:

20°F DB outdoors
70°F DB indoors.

On the day following the heating test, the 95°DB, 80°DB and 50 percent RH conditions were reestablished to test again for charge. A small loss was noted, but because a number of hours had elapsed since the heating test and since there was no indication of loss of charge during the test itself, the refrigerant charge during heating was considered essentially the same as that used for the cooling test.

Steady state conditions were maintained for more than an hour before each test. During the cooling test, readings were taken every ten minutes for three hours and 40 minutes and during the heating test, every ten minutes for two hours and 40 minutes. In each case, the hour representing the steadiest conditions was used for evaluating performance.

The same motor pulley setting for the indoor blower was used for both the cooling and heating tests. In the cooling test this setting resulted in a cfm of 1256 and in the heating test a cfm of 1345. Thus a heat pump in a home at the Seymour Johnson Air Force Base will have a somewhat higher air circulation rate on the heating cycle than on the cooling cycle for the same static pressure at the unit outlet.

Throughout the test a pressure difference of 20 psi existed between the compressor discharge and the liquid line entering the coil of the indoor unit as measured by calibrated pressure gages. This difference was estimated to be 10 psi greater than would normally be caused by the elements of the heat pump system such as the dryer, four-way valve, etc. The

oil separator was not in the line and the pressure drop as measured by gages across the flowmeter was negligible.

Representatives of the Mathes Company were aware of this condition, but in the interest of saving time and realizing the loss of capacity would not be great, chose to go ahead with the test without alterations.

The length of both the liquid line and the vapor line during the tests was approximately the same as in the installations at Seymour Johnson Air Force Base, or about 35 ft from outdoor unit to indoor unit.

Because of interference with thermocouple arrangement, the louvered door covering the intake filter of the indoor unit was left off the unit during the tests. The change in performance due to this deviation from normal installation procedures was negligible.

During the tests, power consumed by the indoor blower, outdoor fan, and compressor was read from separate watthour meters. Simultaneous readings were made of currents and voltages. The various meters, together with other instruments for measuring temperature, humidity and pressure are shown in figure 6.

4. TEST RESULTS

A. Cooling Test

ASRE Standard 16-56 requires that values obtained by the psychrometric and flowmeter methods be averaged to obtain the rated capacity of the unit. The results obtained by the two measuring methods during the cooling test, and the total rated cooling capacity of the Model 38HAR-VEB-HP are shown below. This capacity, it will be noted, includes a correction for deviation of barometric pressure from standard barometric pressure. This is in accordance with ASRE 16-56 which allows an increase of 0.8 percent of capacity for each inch of barometer reading below 29.92 in. of Hg during the cooling test.

Summary of Cooling Capacity Values (Btu/hr)

	Test Value	Rounded Value
By psychrometric method	34,440	
By flowmeter method	34,200	
Average	34,320	
Correction for deviation of barometric pressure from standard barometric pressure	180	
	34,500	34,500

Following is a summary of the averages of the more significant data observed during the cooling test.

Psychrometric Method

Temperatures (°F)

At inlet to enclosure around indoor unit	79.9 DB
At outlet of indoor unit in duct	61.3 DB
Temperature difference across indoor coil	18.6 DB
At inlet to outdoor unit	95.4 DB

Relative Humidities (%)

At inlet to enclosure around indoor unit	50.1
At outlet of indoor unit in duct	83.7

Static Pressure across Nozzle (In. of H_2O) 1.36

Volume Air Flow at Nozzle (cfm) 1256

Mass Air Flow at Nozzle (lb of dry air/hr) 5519

Barometric Pressure (In. of Hg) 29.25

Diameter of Nozzle (In.)	7.03
Nozzle Coefficient	.99
Static Resistance (In. of H_2O)	0.20

Flowmeter Method (Refrigerant Method)

Temperatures (°F)	
In liquid line entering coil of indoor unit	108.8
In vapor line leaving coil of indoor unit	47.1
Pressures (psig)	
In liquid line entering coil of indoor unit	268.5
In vapor line leaving coil of indoor unit	78.5
Potter Meter Count for 10 Minutes	323.5*
Other Temperatures (°F)	
In vapor line halfway to outdoor unit	51.2
In suction line at compressor	61.1
Other Pressures (psig)	
Compressor discharge	288.5
Difference in pressure across flowmeter was negligible.	
Motor Power Consumption (Watts)	
Indoor blower	491
Outdoor fan	436
Compressor	3983
Total	4910
Coefficient of Performance	2.06

* Refrigerant flow, gal/min = $\frac{\text{Meter count (1 min. x 100)}}{3365.5}$

Motor Voltages (Volts)

Indoor blower	231.5
Outdoor fan	231.0
Compressor	230.7

Motor Current (Amperes)

Indoor blower	2.99
Outdoor fan	2.63
Compressor	18.11

B. Heating Test

The heating test gave the following results. The correction shown for deviation of barometric pressure from standard barometric pressure is in accordance with ASRE 16-56, which allows an increase of 2.0 percent of capacity for each inch of deviation below standard barometric pressure for the heating condition. It will be noted that this allowance is proportionately higher than that for the cooling condition.

Summary of Heating Capacity Values (Btu/hr)

	Test Value	Rounded Value
By psychrometric method	24,000	
By flowmeter method	23,440	
Average	23,720	
Correction for deviation of barometric pressure during test from standard barometric pressure	320	
	24,040	24,000

Following is a summary of the averages of the more significant data observed during the heating test.

Psychrometric Method

Temperatures (°F)

At inlet to enclosure around indoor unit	70.1 DB
At outlet of indoor unit in duct	87.5 DB
Temperature difference across indoor coil	17.4 DB
At inlet to outdoor unit	19.9 DB

Relative Humidity of Indoor Air in Duct (%)	12.0
Static Pressure across Nozzle (In. of H_2O)	1.50
Volume Air Flow at Nozzle (cfm)	1345
Mass Air Flow at Nozzle (lb of dry air/hr)	5725
Barometric Pressure (In. of Hg)	29.40
Diameter of Nozzle (In.)	7.03
Nozzle Coefficient	.99
Static Resistance (In. of H_2O)	.20

Flowmeter Method (Refrigerant Method)

Temperatures (°F)

In vapor line entering coil of indoor unit	114.4
In liquid line leaving coil of indoor unit	81.5

Pressures (psig)

In vapor line entering coil of indoor unit	195.0
In liquid line leaving coil of indoor unit	194.0

Potter Meter Count for 10 Minutes	151.8*

$$* \text{ Refrigerant flow, gal/min} = \frac{\text{Meter count for 1 min x 100}}{3365.5}$$

Other Pressures (psig)

Compressor discharge pressure	197.5
Suction pressure	30.5
Difference in pressure across the flowmeter was negligible.	

Other Temperatures (°F)

Compressor discharge	141.5
Suction line at compressor	5.9

Motor Power Consumption (Watts)

Indoor blower	479
Outdoor fan	589
Compressor	2587
Total	3655

Coefficient of Performance (Exclusive of Strip Heater) 1.91

Motor Voltages (Volts)

Indoor blower	230.1
Outdoor fan	231.1
Compressor	230.0

Motor Current (Amperes)

Indoor blower	2.92
Outdoor fan	3.30
Compressor	12.00

Power Consumption of Strip Heaters

Readings of the energy dissipated by the two strip heaters which came with the indoor unit were made every fifteen minutes for a period of one hour with the following results:

Watthour meter value (Watts)	3339
Average terminal voltage (Volts)	229.8
Average current (Amperes)	14.36
Voltage times current (Watts)	3300

The specified capacity for these two heaters given in heat equivalent values is 12,286 Btu/hr. The observed capacity shown above is equivalent to 11,396 Btu/hr. Four heaters, of course, each having the same power consumption would dissipate twice this amount or 22,792 Btu as compared with the specification heat equivalent value of 24,572 Btu/hr noted in Section I, Introduction.

C. Heating Test at 30°F

At the request of the Mathes Company, data were taken at 30° during the lowering of the outdoor temperature for the heating test. Readings were made every ten minutes for a full hour, preceded by a steady-state period of about 20 minutes.

Results of the test at this condition are given below.

	Test Value	Rounded Value
Psychrometric method	27,430	
Flowmeter method	26,640	
Average	27,035	
Correction for deviation of barometric pressure during test from standard barometric pressure	410	
	27,445	27,400

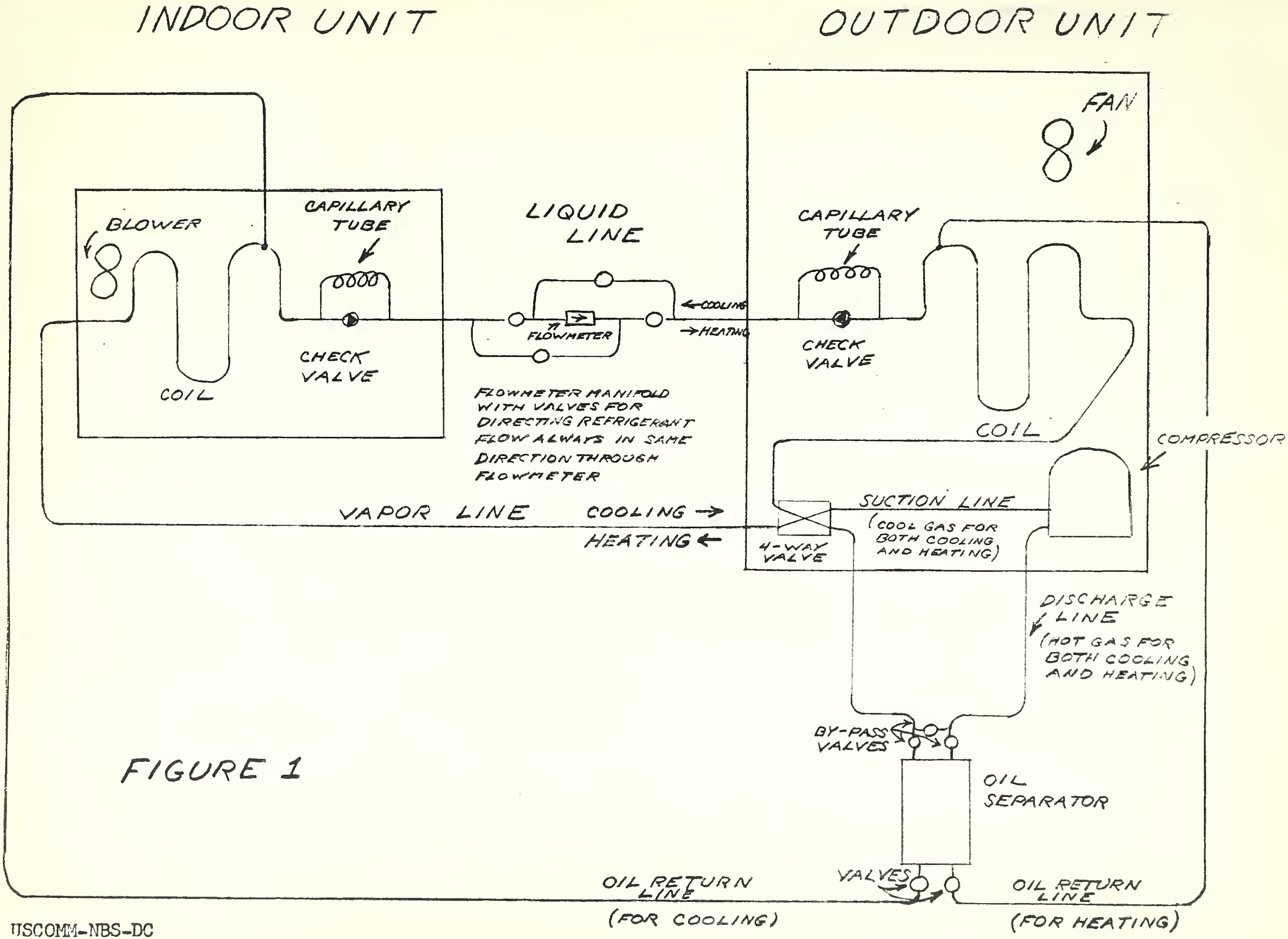

FIGURE 1

USCOMM-NBS-DC

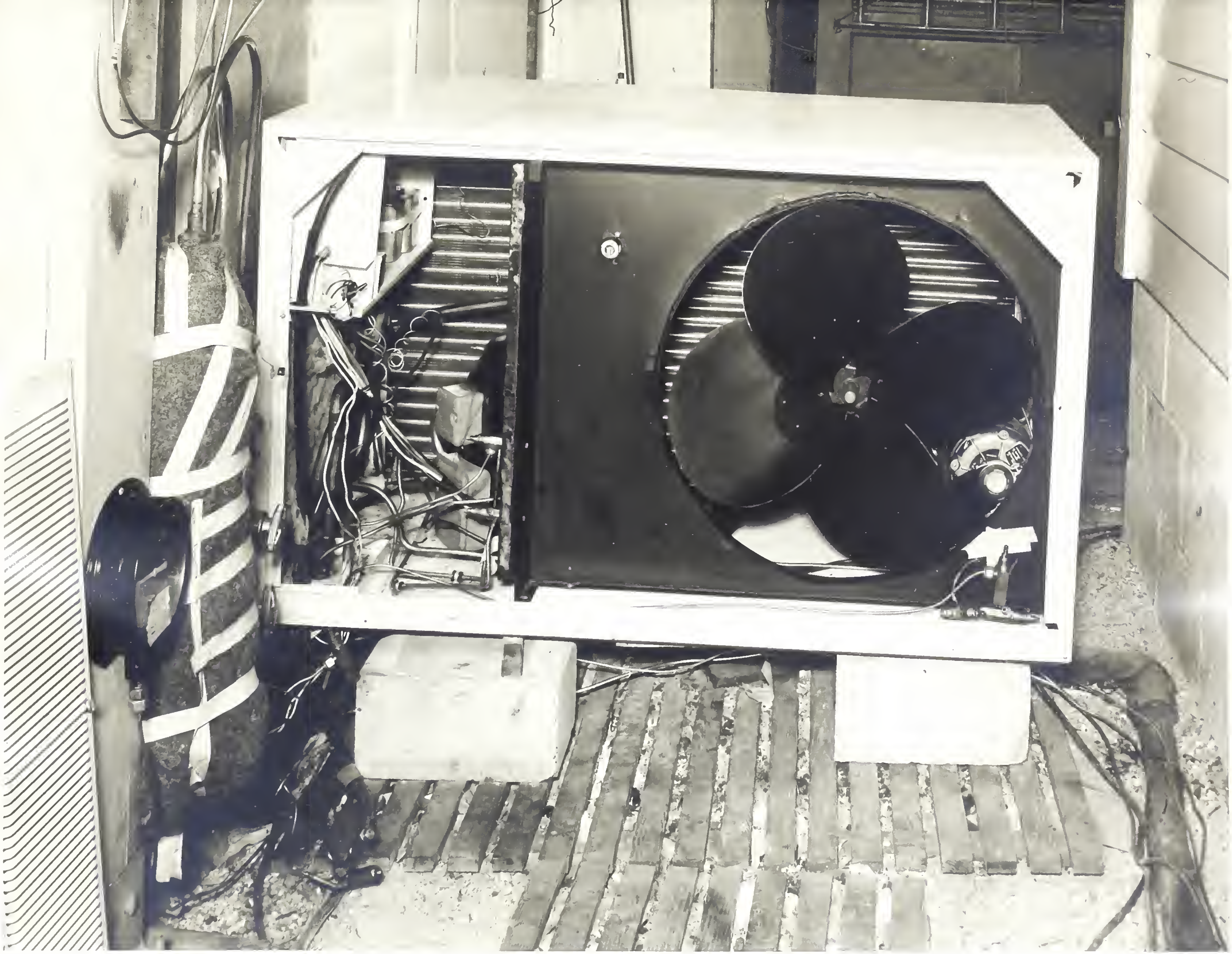

Figure 2

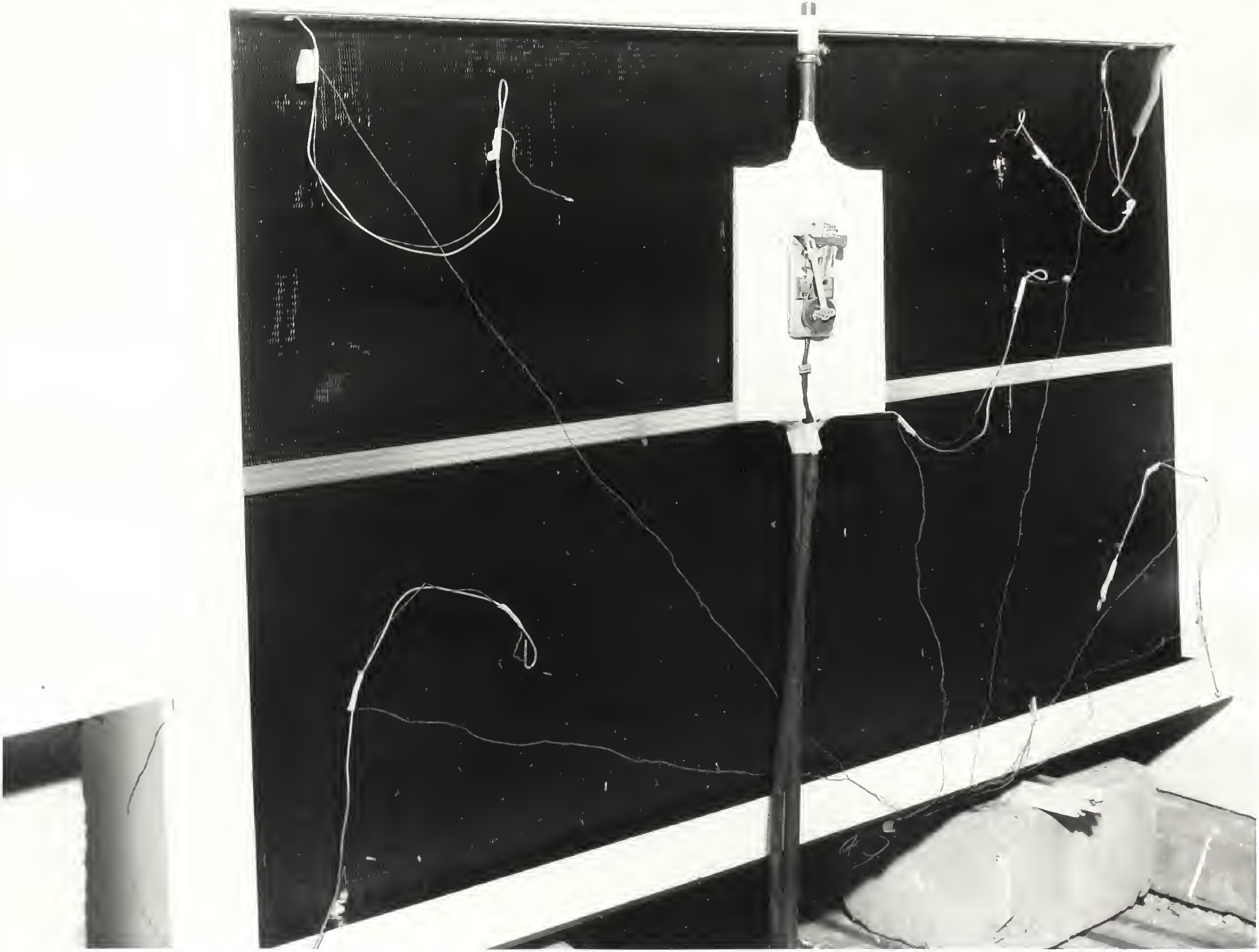

Figure 3

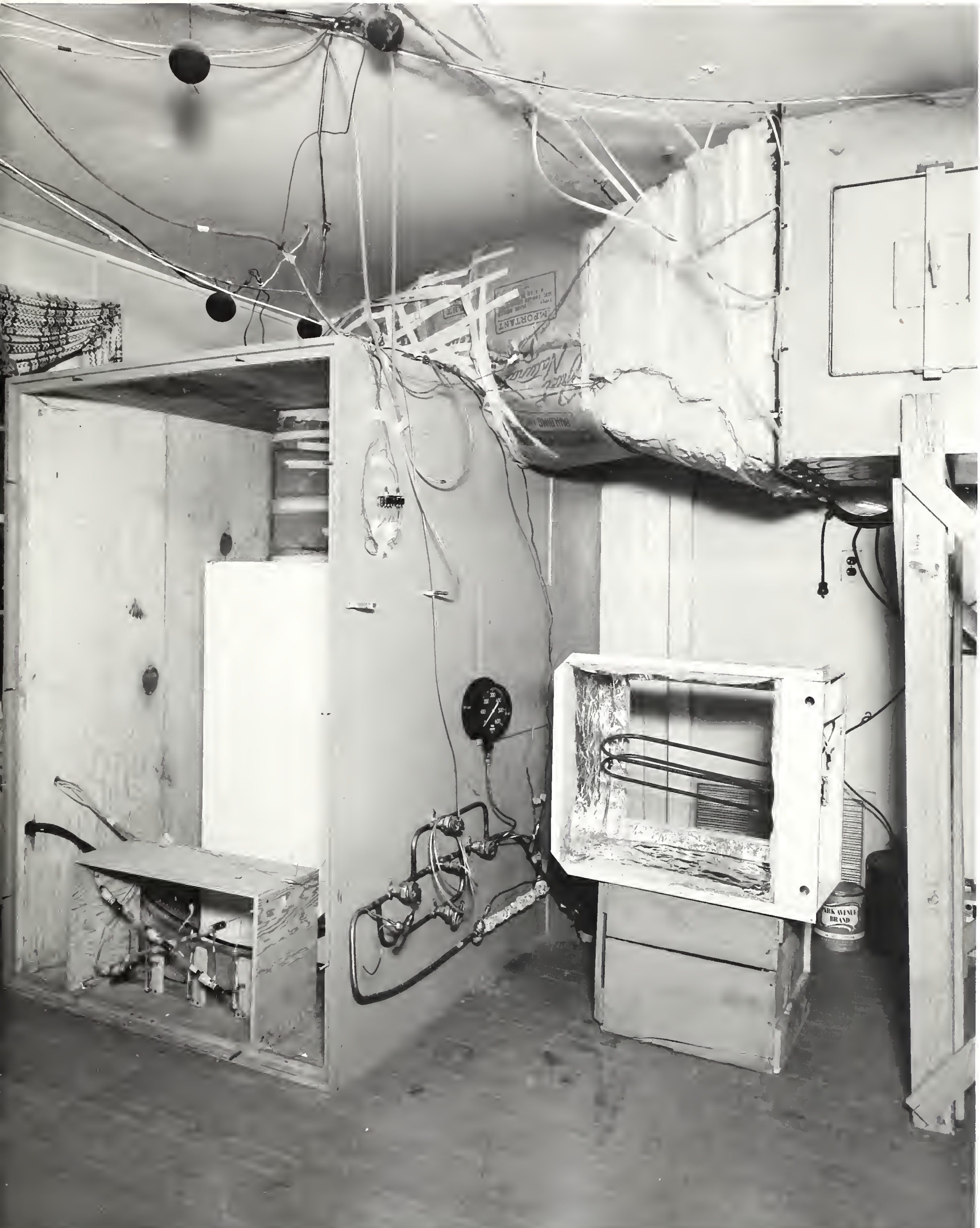

Figure 4

Standards.

Figure 5

Standards.

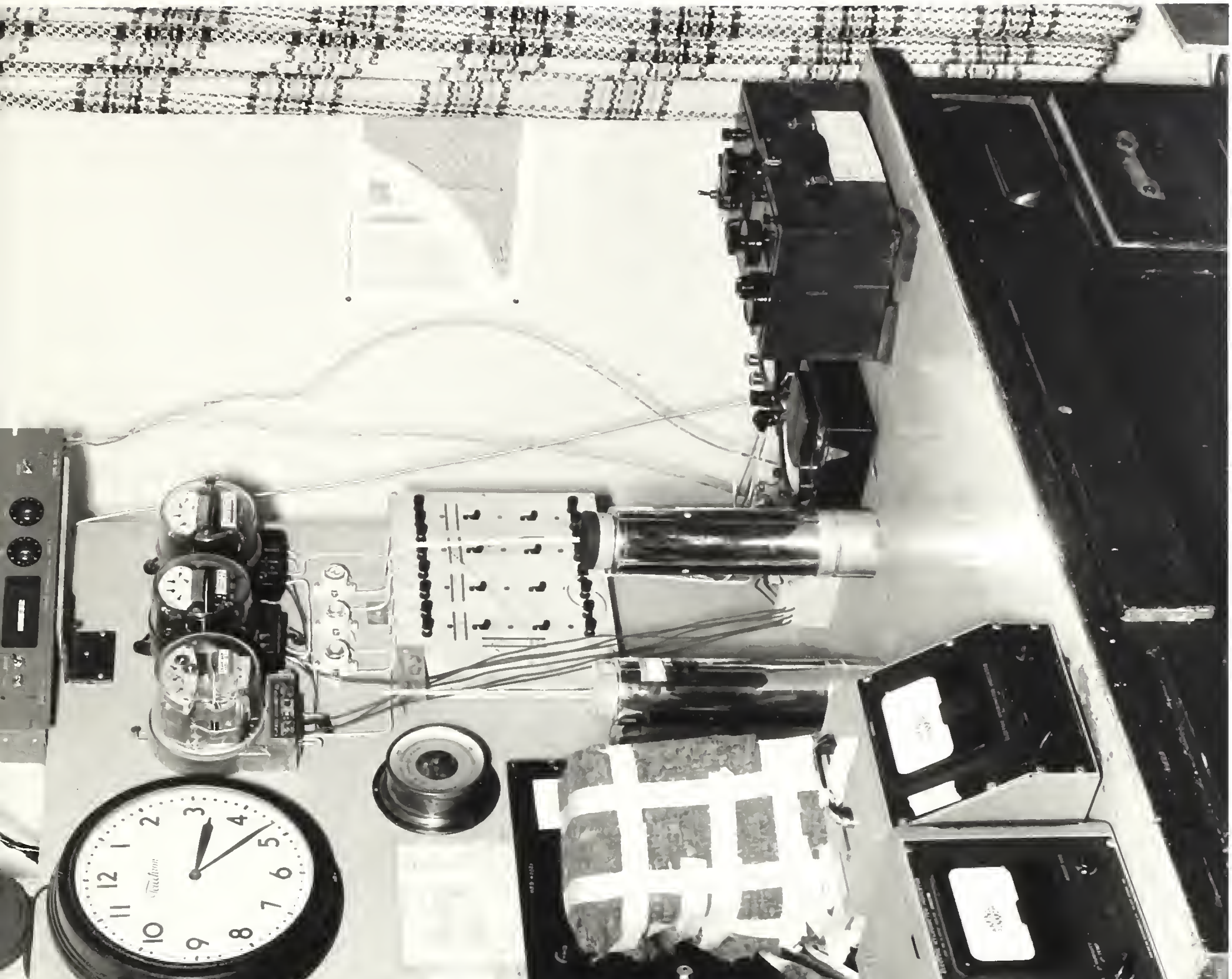

Figure 6

Standards.

U. S. DEPARTMENT OF COMMERCE
Sinclair Weeks, *Secretary*

NATIONAL BUREAU OF STANDARDS
A. V. Astin, *Director*

THE NATIONAL BUREAU OF STANDARDS

The scope of activities of the National Bureau of Standards at its headquarters in Washington, D. C., and its major laboratories in Boulder, Colo., is suggested in the following listing of the divisions and sections engaged in technical work. In general, each section carries out specialized research, development, and engineering in the field indicated by its title. A brief description of the activities, and of the resultant publications, appears on the inside front cover.

WASHINGTON, D. C.

Electricity and Electronics. Resistance and Reactance. Electron Devices. Electrical Instruments. Magnetic Measurements. Dielectrics. Engineering Electronics. Electronic Instrumentation. Electrochemistry.
Optics and Metrology. Photometry and Colorimetry. Optical Instruments. Photographic Technology. Length. Engineering Metrology.
Heat. Temperature Physics. Thermodynamics. Cryogenic Physics. Rheology. Engine Fuels. Free Radicals Research.
Atomic and Radiation Physics. Spectroscopy. Radiometry. Mass Spectrometry. Solid State Physics. Electron Physics. Atomic Physics. Neutron Physics. Nuclear Physics. Radioactivity. X-rays. Betatron. Nucleonic Instrumentation. Radiological Equipment.
Chemistry. Organic Coatings. Surface Chemistry. Organic Chemistry. Analytical Chemistry. Inorganic Chemistry. Electrodeposition. Molecular Structure and Properties of Gases. Physical Chemistry. Thermochemistry. Spectrochemistry. Pure Substances.
Mechanics. Sound. Mechanical Instruments. Fluid Mechanics. Engineering Mechanics. Mass and Scale. Capacity, Density, and Fluid Meters. Combustion Controls.
Organic and Fibrous Materials. Rubber. Textiles. Paper. Leather. Testing and Specifications. Polymer Structure. Plastics. Dental Research.
Metallurgy. Thermal Metallurgy. Chemical Metallurgy. Mechanical Metallurgy. Corrosion. Metal Physics.
Mineral Products. Engineering Ceramics. Glass. Refractories. Enameled Metals. Concreting Materials. Constitution and Microstructure.
Building Technology. Structural Engineering. Fire Protection. Air Conditioning, Heating, and Refrigeration. Floor, Roof, and Wall Coverings. Codes and Safety Standards. Heat Transfer.
Applied Mathematics. Numerical Analysis. Computation. Statistical Engineering. Mathematical Physics.
Data Processing Systems. SEAC Engineering Group. Components and Techniques. Digital Circuitry. Digital Systems. Analog Systems. Application Engineering.

- Office of Basic Instrumentation.
- Office of Weights and Measures.

BOULDER, COLORADO

Cryogenic Engineering. Cryogenic Equipment. Cryogenic Processes. Properties of Materials. Gas Liquefaction.
Radio Propagation Physics. Upper Atmosphere Research. Ionospheric Research. Regular Propagation Services. Sun-Earth Relationships. VHF Research.
Radio Propagation Engineering. Data Reduction Instrumentation. Modulation Systems. Navigation Systems. Radio Noise. Tropospheric Measurements. Tropospheric Analysis. Radio Systems Application Engineering. Radio Meteorology.
Radio Standards. High Frequency Electrical Standards. Radio Broadcast Service. High Frequency Impedance Standards. Calibration Center. Microwave Physics. Microwave Circuit Standards.

NBS